(4-1)Introduction :

A radiation dosimeter is a device, instrument or system that measures or evaluates, either directly or indirectly, the quantities exposure, kerma, absorbed dose or equivalent dose, or their time derivatives (rates), or related quantities of ionizing radiation. A dosimeter along with its reader is referred to as a dosimetry system. Measurement of a dosimetric quantity is the process of finding the value of the quantity experimentally using dosimetry systems. The result of a measurement is the value of a dosimetric quantity expressed as the product of a numerical value and an appropriate unit. To function as a radiation dosimeter, the dosimeter must possess at least one physical property that is a function of the measured dosimetric quantity and that can be used for radiation dosimetry with proper calibration. In order to be useful, radiation dosimeters must exhibit several desirable characteristics. For example, in radiotherapy exact knowledge of both the absorbed dose to water at a specified point and its spatial distribution are of importance, as well as the possibility of deriving the dose to an organ of interest in the patient. In this context, the desirable dosimeter properties will be characterized by accuracy and precision, linearity, dose or dose rate dependence, energy response, directional dependence and spatial resolution.

(4-2) External exposure :

occurs when all or part of the body is exposed to a penetrating radiation field from an external source. During exposure this radiation can be absorbed by the body or it can pass completely through, similar to a chest x-ray. Note that exposure to a radiation field does not cause an individual to become radioactive; the radiation exposure ceases as soon as the individual leaves the radiation field . All ionizing radiation sources produce an external radiation field . However, some fields are so small they pose no external radiation risk at all . Examples include these low and moderate energy beta radiation emitters:

- H-3
- C-14
- Ni-63

- P-33
- S-35

Other sources of ionizing radiation produce much higher energy external radiation fields, and care must be taken to shield the source and to monitor exposure while working near these sources. Examples include:

- Am-241/Be neutron sources
- P-32 beta sources
- Cs-137 gamma sources
- Co-60 gamma sources
- X-ray machines (only when the machine is energized)

(4-3) Internal exposure :

The other type of radiation injury involves contamination with radioactive material. Contamination means that radioactive material in the form of gases, liquids, or solids are released into the environment and contaminate people externally (such as on the skin), internally (such as by ingestion), or both.

Contamination by radioactive material can lead to incorporation of radioactive material into the body. This can be the result of uptake of radioactive material by body cells, tissues, and target organs such as bone, liver, thyroid, or kidney. In general, radioactive materials are distributed throughout the body based upon their chemical properties. For example, radioiodine, such as ^{125}I, is concentrated in the thyroid gland of the body, just as non-radioactive iodine does.

All radioisotopes are potentially hazardous if inhaled or ingested. This includes low energy isotopes such as ^{3}H and ^{14}C. Frequent monitoring for contamination is necessary when working with any unsealed isotopes, and periodic leak tests are conducted for sealed sources (usually every 6 months).

X-ray machines contain no radioactive material, and thus pose no threat of contamination even when energized. When energized, an x-ray machine is a source of external radiation exposure .

(4-4) Radiation protection methods:

One of the best ways to prepare is to understand the principles of radiation protection in terms of time, distance and shielding. During radiological emergencies (which constitutes a large release of radioactive materials into the environment)

• **Time:** For people who are exposed to radiation in addition to normal background radiation, limiting or decreasing the radiation time reduces the dose from the radiation source.

• **Distance:** Just as the heat from fire decreases when you move away from it, the radiation dose decreases dramatically with increasing distance between you and the source.

• **Shielding:** Provide barriers of lead or concrete (concrete) or water protection from the penetration of gamma rays and X-rays. This is the reason why some radioactive materials are stored under water or in concrete or lead-lined rooms, and why dentists place a blanket made of lead over patients who receive x-rays of their teeth. Therefore, proper shielding between you and the source of radiation will result in a significant reduction or elimination of the dose.

(4-5) Radiation dose :

Radiation dose is a measure of the amount of exposure to radiation. There are three kinds of dose in radiological protection . Absorbed dose is a measureable, physical quantity, while equivalent dose and effective dose are specifically for radiological protection purposes . .
Effective dose in particular is a central feature of radiological protection . It sums up any number of different exposures into a single number that reflects, in a general way, the overall risk . The concept may be complex, but it makes radiological protection practical to implement .

(4-6)Absorbed Dose :

Absorbed dose is the amount of energy deposited by radiation in a mass. The mass can be anything: water, rock, air, people, etc. Absorbed dose is expressed in milligrays (mGy) . Or Absorbed dose is defined as the amount of energy deposited by ionizing radiation in a substance . Absorbed dose is given the symbol **D**. The absorbed dose is usually

measured in a unit called the **gray** (Gy), which is derived from the SI system. The non-SI unit **rad** is sometimes also used, predominantly in the USA.

$$D = \frac{\Delta E_D}{\Delta m} \quad \left[\frac{J}{kg}\right]$$

Units of absorbed dose:

- **Gray**. A dose of one gray is equivalent to a unit of energy (joule) deposited in a kilogram of a substance.
- **RAD**. A dose of one rad is equivalent to the deposition of one hundred ergs of energy in one gram of any material.

The **absorbed dose rate** is the rate at which an absorbed dose is received. It is a measure of radiation dose intensity (or strength). The absorbed dose rate is therefore defined as:

$$\dot{D} = \frac{\Delta D}{\Delta t} \quad \left[\frac{J}{kg.sec}\right]$$

In conventional units, it is measured in mrad/sec**,** rad/hr, mGy/sec or Gy/hr. Since the amount of radiation exposure depends directly (linearly) on the time people spend near the source of radiation, the absorbed dose is equal to the strength of the radiation field (dose rate) multiplied by the length of time spent in that field. The example above indicates a person could expect to receive a dose of 25 millirems by staying in a 50 millirems/hour field for thirty minutes .

Assume the point isotropic source which contains 1.0 Ci of ^{137}Cs, which has a half-life of 30.2 years. Note that the relationship between half-life and the amount of a radionuclide required to give an activity of one curie is shown below. This amount of material can be calculated using λ, which is the decay constant of certain nuclide:

$$N(atoms)\ x\ \lambda(s^{-1}) = 1\ Ci = 3.7\ x\ 10^{10}\ Bq$$

(4-7) Equivalent Dose :

Equivalent dose is calculated for individual organs. It is based on the absorbed dose to an organ, adjusted to account for the effectiveness of the type of radiation . Equivalent dose (symbol H_T) is a dose quantity calculated for individual organs (index T–tissue). The equivalent dose is based on the absorbed dose to an organ, adjusted to account for the effectiveness of the type of radiation **.** An equivalent dose is given the symbol H_T. The SI unit of $\mathbf{H_T}$ is the **sievert** (Sv) or but rem (roentgen equivalent man) is still commonly used (**1 Sv = 100 rem**). The weighted dose was designated as the organ- or tissue equivalent dose :

$$\mathbf{H_T = \sum W_R D_{TR}}$$

D : the absorption dose
W_R : radiation weight factor or Specific factor.

The following table shows the quality factor:

item	Type of radiation	Quality factor
1-	X-rays, beta particles, and gamma rays.	1
2-	Thermal neutrons and low-energy protons (keV).	2-5
3-	Thermal neutrons and high-energy protons (MeV).	5-10
4-	Heavy ions, alpha particles.	20

Example :

In one of the nuclear laboratories, the lungs of one of the workers were exposed to the following doses: (0.02Gy) and (2 rad) with thermal neutrons, i.e., with an energy of less than 10 kiloelectron volts, and (0.05Gy) and (5 rad) with thermal neutrons with an energy of 14, (0.8 Gy) and (80rad) by gamma radiation. Calculate the equivalent dose for the lungs of this worker ?

Sol :

$H_T = \sum W_R D_{TR}$

$= 5 \times 0.02 + 10 \times 0.05 + 1 \times 0.8$

$= 0.1 + 0.5 + 0.8$

$= 1.4$ (Sv)

A dose of one Sv caused by gamma radiation is equivalent to an energy deposition of one joule in a kilogram of tissue. That means one sievert is equivalent to one gray of gamma rays deposited in certain tissue. On the other hand, similar biological damage (one sievert) can be caused only by 1/20 gray of alpha radiation.

One sievert is a large amount of equivalent dose. A person who has absorbed a whole-body dose of 1 Sv has absorbed one joule of energy in each kg of body tissue (in case of gamma rays).

Equivalent doses measured in industry and medicine often have usually lower doses than one sievert, and the following multiples are often used:

1 mSv (millisievert) = 10^{-3} Sv

1 µSv (microsievert) = 10^{-6} Sv

Conversions from the SI units to other units are as follows:

- 1 Sv = 100 rem
- 1 mSv = 100 mrem
- 1 Gy = 100 rad

(4-8) Equivalent Dose Rate

The equivalent dose rate is the rate at which an equivalent dose is received and a measure of radiation dose intensity (or strength). The equivalent dose rate is therefore defined as:

$$\dot{H}_T = \sum_R w_R \dot{D}_{T,R}$$

where

- $\dot{D}_{T,R}$ is the absorbed dose rate averaged over the tissue or organ, T, due to the incident radiation, R.
- w_R the radiation weighting factor.

(4-9) Effective Dose :

Effective dose is calculated for the whole body. It is the addition of equivalent doses to all organs, each adjusted to account for the sensitivity of the organ to radiation . Effective dose is expressed in millisieverts (mSv) . Equivalent dose is expressed in millisieverts (mSv) to an organ .

Ionizing radiation deposits energy in the matter being irradiated. The quantity used to express this is the absorbed dose, a physical dose quantity that is dependent on the level of incident radiation and the absorption properties of the irradiated object. Absorbed dose is a physical quantity, and is not a satisfactory indicator of biological effect, so to allow consideration of the stochastic radiological risk, the dose quantities equivalent dose and effective dose were devised by the International Commission on Radiation Units and Measurements (ICRU) and the ICRP to calculate the biological effect of an absorbed dose.

$$\mathbf{E = \sum_T W_T H_T}$$

To obtain an effective dose, the calculated absorbed organ dose D_T is first corrected for the radiation type using factor W_R to give a weighted average of the equivalent dose quantity H_T received in irradiated body tissues, and the result is further corrected for the tissues or organs being irradiated using factor W_T, to produce the effective dose quantity E .

Example :

The tissues of a medical laboratory technician were exposed, during a year, due to the introduction of radioactive materials and due to external exposure, to the following doses: (150 mrem) and (1.5msv) for the lungs, (500 mrem) and (5 msv)for the stomach , (100 mrem) and (1 msv) for the duodenum, and (250 mrem) and (2.5 msv) for the colon, And (50 mrem) and (0.5 msv) for the gonads.

Sol :

$E = \sum_T W_T H_T$

= 0.12 x150 +0.12 x 5 +0.05 x 1 + 0.12 x 2.5 +0.20 x 0.5

= 0.18 + 0.60 +0.05 +0.30 +0.10

= 1.23 m Sv

(4-10) Use of tissue weighting factor W_T

The ICRP tissue weighting factors are given in the accompanying table, and the equations used to calculate from either absorbed dose or equivalent dose are also given.

Some tissues like bone marrow are particularly sensitive to radiation, so they are given a weighting factor that is disproportionately large relative to the fraction of body mass they represent. Other tissues like the hard bone surface are particularly insensitive to radiation and are assigned a disproportionally low weighting factor.

Definition :

absorbed dose The energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the rad and the gray (Gy).

activity The rate of disintegration (transformation) or decay of radioactive material. The units of activity are the curie (Ci) and the becquerel (Bq).

As Low As Reasonably Achievable (ALARA) – Making every reasonable effort to maintain exposures as far below the dose limits as is practical, taking into account economic considerations and other societal concerns.

becquerel (Bq) The SI unit of activity. 1 Bq equals 1 disintegration per second.

byproduct material As used in the Atomic Energy Act:

(1)- Any radioactive material (except special nuclear material) yielded in, or made radioactive by, exposure to the radiation incident to the process of producing or using special nuclear material

(2)-The tailings or wastes produced by the extraction or concentration of uranium or thorium from ore processed primarily for its source-material content, including discrete surface wastes resulting from uranium-solution extraction processes. Underground ore bodies depleted by solution-extraction operations do not constitute byproduct material according to this definition.

collective dose The sum of the individual doses received in a given period by a specified population from exposure to a specified source of radiation.

committed dose equivalent ($H_{T,50}$) The dose equivalent to organs or tissues of reference (T) that will be received from an intake of radioactive material by a person during the 50-y period after the intake.

committed effective dose equivalent ($H_{E,50}$) The sum of the products, for each body organ or tissue that is irradiated, of the applicable weighting factor and the committed dose equivalent to the organ or tissue ($H_{E,50} = \Sigma w_T H_{T,50}$).

curie (Ci) The conventional unit of activity. 1 Ci equals 3.7×10^{10} disintegrations per second, which equals 3.7×10^{10} Bq.

dose or **radiation dose** A generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose equivalent.

dose equivalent (H_T) The product of the absorbed dose in tissue, the quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and the sievert (Sv).

effective dose (E) The sum of weighted equivalent doses to all tissues and organs of the body (ICRP 1991). $E = \Sigma w_T H_T$, where H_T is the equivalent dose and w_T is the tissue weighting factor.

effective dose equivalent (H_E) The sum of the products, for each body organ or tissue that is irradiated, of the dose equivalent to the organ or tissue and the applicable weighting factor ($H_E = \Sigma w_T H_T$).

equivalent dose (H_T) In radiation protection, the absorbed dose averaged over a tissue or organ rather than a point, as is the case for dose equivalent) and weighted for the radiation quality that is of interest. For this quantity, the weighting factor is called the radiation weighting factor instead of the quality factor, as used in earlier dosimetric quantities.

external dose The dose received from radiation sources outside the body.

exposure A quantity used to express external ionizing radiation, or to indicate presence of radionuclides or radiation affecting individuals or populations (for example, "exposure" to radionuclides in the environment).

gray (Gy) The SI unit of absorbed dose. 1 Gy equals an absorbed dose of 1 J/kg (100 rad).

internal dose The dose received from radioactive material taken into the body.

limits (dose limits) The permissible upper bounds of radiation doses.

member of the public Any person except when that person is receiving an occupational dose.

quality factor (Q) The modifying factor that is used to derive dose equivalent from absorbed dose for purposes of radiation protection.

rad The special unit of absorbed dose. 1 rad equals an absorbed dose of 100 ergs per gram or 0.01 J per kg (0.01 Gy).

radiation (ionizing radiation) Alpha particles, beta particles, gamma rays, x rays, neutrons, high-energy electrons, high-energy protons, and other particles capable of producing ionization in matter. (As used in this report, radiation does not include nonionizing radiation, such as radiowaves, microwaves, visible, infrared, or ultraviolet light.)

reference man A hypothetical aggregation of human physical and physiologic characteristics arrived at by international consensus. These characteristics can be used by researchers and public-health workers to standardize results of experiments and to relate biologic insult to a common base.

relative biological effectiveness (RBE) The ratio of the absorbed dose of a reference radiation (usually 200 keV x rays) to the absorbed dose of the test radiation required to produce the same degree of biologic effect. The RBE of the test radiation depends on the exact biologic effect in a given species of organism under a given set of exposure conditions.

rem The special unit of any of the quantities expressed as dose quivalent. The dose equivalent equals the product of the absorbed dose in rads and the quality factor (1 rem = 0.01 Sv).

roentgen (R) The unit of exposure. One roentgen equals the amount of x or gamma radiation required to produce ions carrying a charge of 1 electrostatic unit (esu) per cubic centimeter (2.58×10^{-4} coulomb per kg) of dry air under standard conditions.

sievert (Sv) The SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sieverts is equal to the product of the absorbed dose in grays and the quality factor (1 Sv = 100 rem).

source material As defined under the Atomic Energy Act:

(1)-Uranium, thorium, or any combination of uranium and thorium in any physical or chemical form

(2)- Ores that contain, by weight, 0.05% or more of uranium, thorium, or any combination thereof. Source material does not include special nuclear material.

special nuclear material As defined under the Atomic Energy Act:

(1)- Plutonium, uranium-233, uranium enriched in uranium-233 or in uranium-235, and any other material that the Nuclear Regulatory Commission, pursuant to the provisions of Section 51 of the act, determines to be special nuclear material, but not including source material

(2)-Any material artificially enriched by any of the foregoing, but not including source material .

Total Effective Dose Equivalent (TEDE) The sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). It is a term used by some organizations to emphasize that the sum of the contributions from external and internal sources is meant. This term is not a part of the recommendations of the ICRP or NCRP. The term *effective dose equivalent,* without the modifier "total," is sufficient to imply contributions from external and internal sources.

uranium fuel cycle The operations of milling of uranium ore, chemical conversion of uranium, isotopic enrichment of uranium, fabrication of uranium fuel, generation of electricity by a light-water-cooled nuclear power plant using uranium fuel, and reprocessing of spent uranium fuel to the extent that these activities directly support the production of electric power for public use. Does not include mining operations, operations at waste-disposal sites, transportation of radioactive material in support of these operations, and the reuse of recovered nonuranium special nuclear and byproduct materials from the cycle.

weighting factor (w_T) For an organ or tissue (T), the proportion of the risk of stochastic effects resulting from irradiation of that organ or tissue to the total risk of stochastic effects when the whole body is irradiated uniformly.

whole body For purposes of external exposure, the head, trunk (including male gonads), arms above the elbow, and legs above the knee.

working level (WL) Any combination of short-lived radon decay products in 1 L of air that will result in the ultimate emission of alpha-particle energy equal to 1.3×10^5 MeV (2.08×10^{-5} J per m^3). Also equals the total energy emitted by alpha particles from short-lived radon decay products in equilibrium with radon gas in air at a concentration of 100 pCi/L (3.7 kBq per m^3).